Guidelines for CubeSat's Thermal Design

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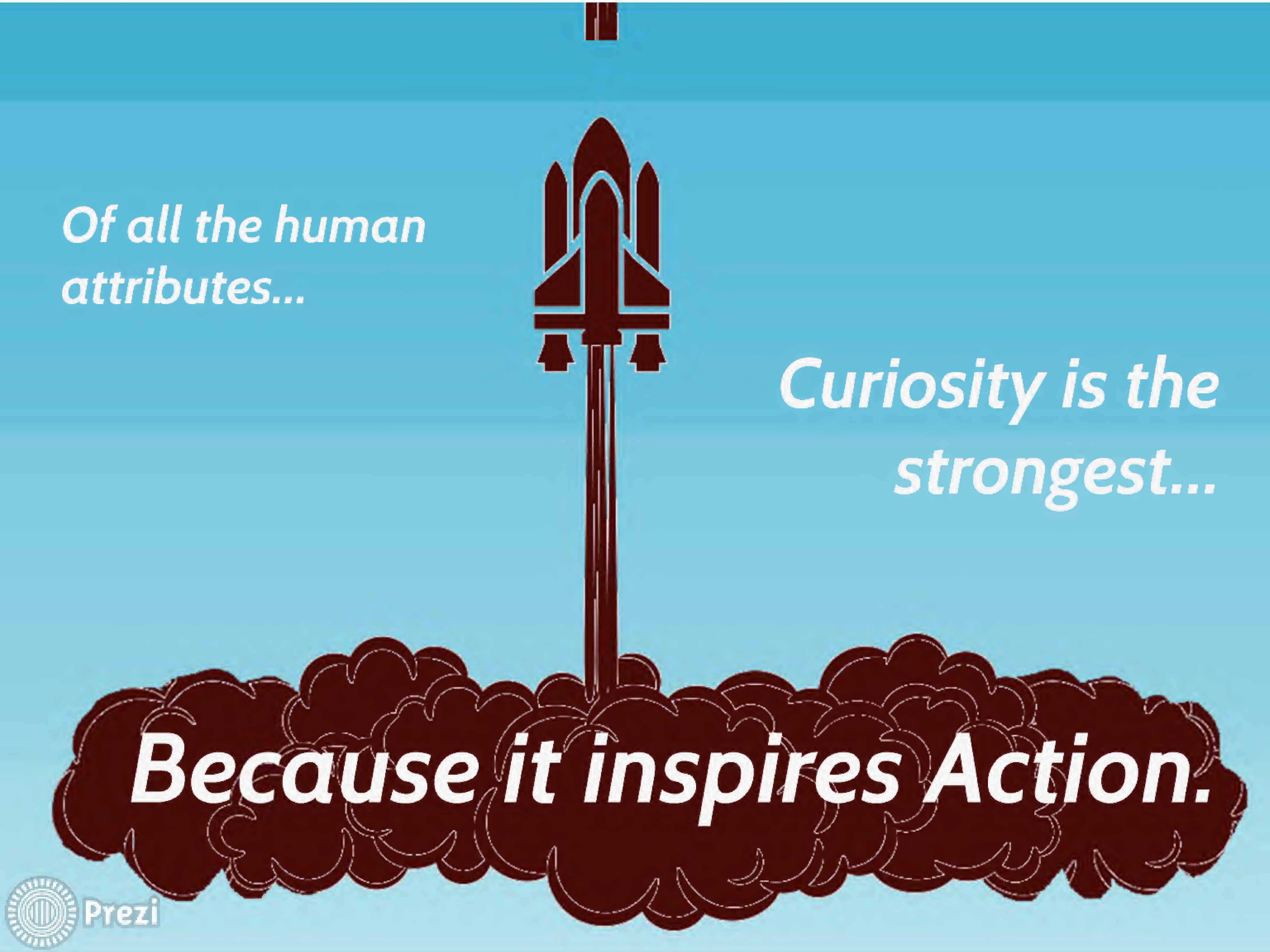
Thermal & Fluids Analysis Workshop 2015

GSFC · 2015


Of all the human attributes...
Curiosity is the strongest...
Because it inspires Action.
Prezi

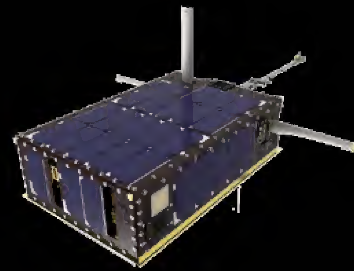
NASA has capitalized on the nation's curiosity through space exploration.

With each launch we hope to answer questions...

To contribute to the advancement of science & technology.

But what about those questions that don't get answered

Because of limited opportunities available with traditional large spacecrafts?



FIREFLY

A collaboration between NASA Goddard and the National Science Foundation to study the link between lightning and terrestrial gamma-ray flashes.

Dellingr

It will carry three heliophysics-related payloads, one of which will measure the densities of all significant neutral and ionized atom species in the ionosphere,

HISTORY

"Doing more with less - in these days of tight budgets and limited funding, that philosophy has become a way of life. At NASA Goddard, this means constantly looking for new ways to be creative and innovative, while taking advantage of every opportunity to reduce development time and costs."

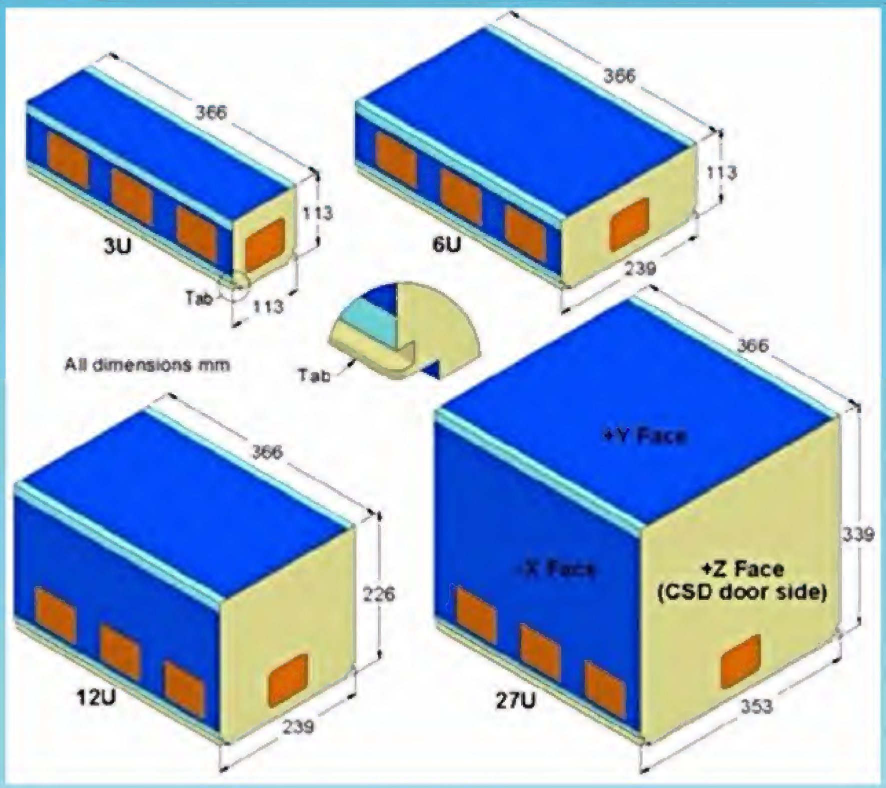
Nona Cheeks
Chief, Innovative Technology Partnerships Office (Code 504)
NASA Goddard

180 kg – 100 kg
Minisatellite

100 kg – 10 kg
Microsatellite

10 kg – 1 kg
Nanosatellite (CubeSat)

<1 kg
Femto and Picosatellite



- Agile low-cost option for enabling scientific discovery, technology, training and education.

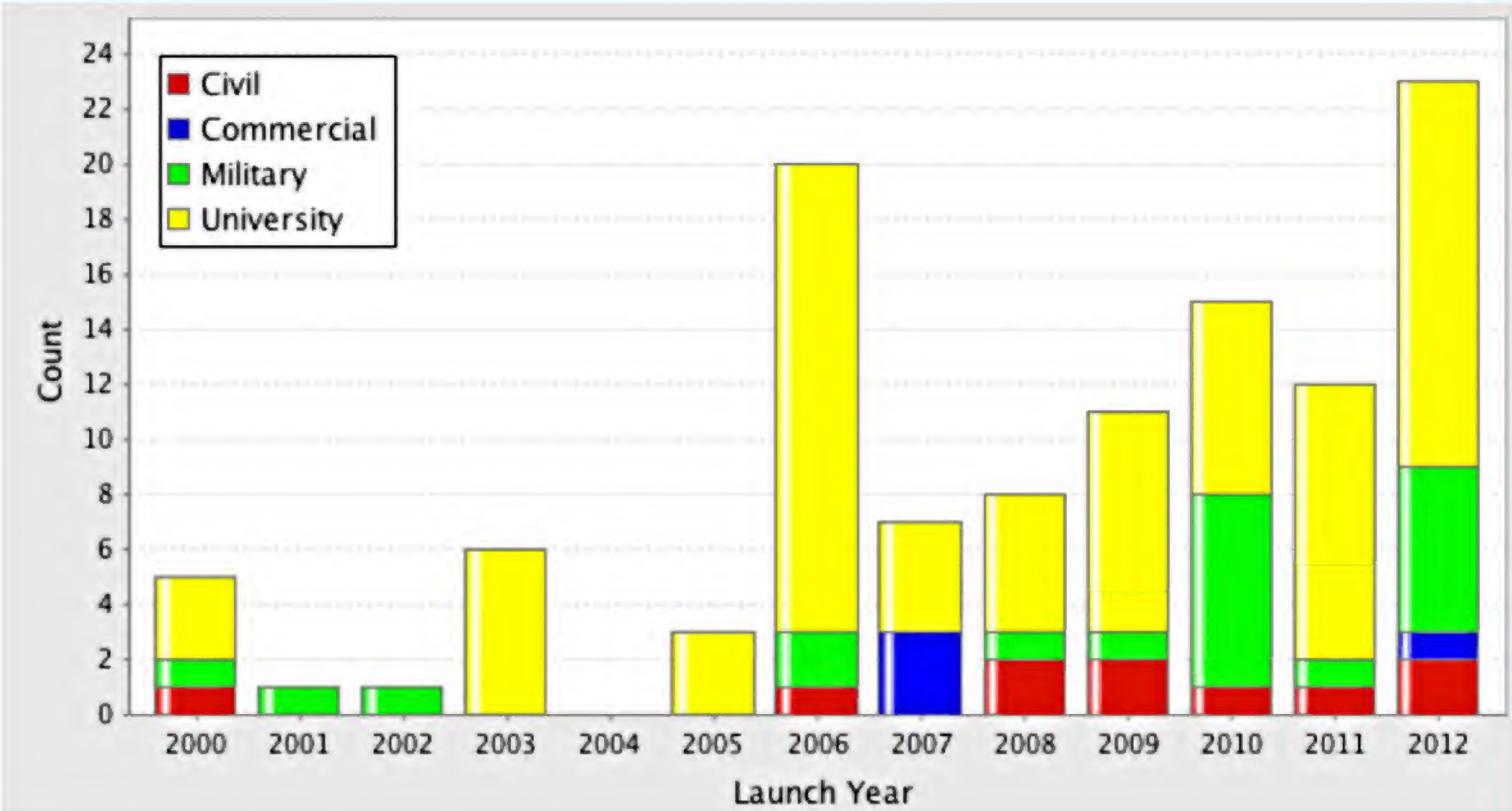


Figure 11. Type of CubeSat Mission Developer by Launch Year

Objective	Launched	Successful	Elements of previous missions
Technology	40 (100%)	12 (50%)	COTS component integration and radiation hardness, experimental sensors, system architectures, radiation and fault tolerance, solar array performance, tethered systems, deployable systems, wireless links, power management
Earth imaging	13 (33%)	5 (21%)	COTS CMOS camera, dedicated processor, attitude determination algorithms
Novel communication	6 (18%)	1 (4%)	Non-AX.25 protocols, active grid and patch antennae, redundant links, advanced modulation techniques
Science	10 (25%)	3 (13%)	Charged particles, solar sailing, earthquakes, airglow, animal tracking, DNA denaturing, gamma-ray bursts, atmospheric GPS scintillation, atomic oxygen, radiation
Other utility	6 (15%)	1 (4%)	Ship AIS monitoring and data relay, risk reduction for future missions or technology demonstration testbed

Table 2: breakdown of mission objectives for CubeSats launched (out of 40) and successful (out of 24)

BENEFITS

Of Bringing CubeSats to Goddard Space Flight Center

SCIENCE Research

- Planetary: exploration dealing with water, atmosphere, environment
- AstroPhysics: development involving optics, distorting lens

Early Career Engineers

- Apply variety of engineering skills
- See mission from start to finish within a year or two

Outreach Opportunities

- NASA has started the CubeSat Launch Initiative (CSLI) to give satellites developed by people outside of the industry a free ride to space
- CSLI, among others, will attract and retaining student in STEM because it promotes and develops early on partnership with NASA

Engineering & Technology

- Building engineering technical skill in new endeavors. For example, finding ways for CubeSats to go beyond low earth orbit (LEO)
- Flying high risk technology on CubeSat can help improve certain technology TRL (Technology Readiness Level)

CHALLENGES & RISKS

A misconception that people usually have is that you can miniaturize everything when you shift from large mission to small mission. For example, the time it takes to develop flight software cannot be "miniaturize."

Aprille Ericsson, Ph.D.
Small Business Innovation Research (SBIR) &
Small Business Technology Transfer (STTR) Program Manager
Innovative Technology Partnerships Office

Class A:
Failure would have extreme consequences to public safety or high priority national science objectives.
Examples: HST and JWST

Class B:
Represents a high priority National asset whose loss would constitute a high impact to public safety or national science objectives.
Examples: GOES-R, TDRS-K/L/M, MAVEN, JPSS, and OSIRIS-REX

Mission Class	Level of Acceptable Risk
A	Minimum Risk
B	Risk/Cost Compromise
C	Single Purpose, Repeat Mission Possible, Some Risk Allowed
D	Routine, Rapid Mission, or Proof of Concept, More Risk Allowed

Class C:
Represents an instrument or spacecraft whose loss would result in a loss or delay of some key national science objectives.
Examples: LRO, MMS, TESS, and ICON

Class D:
Cost/schedule are equal or greater considerations compared to mission success risks
Technical risk is medium by design (may be dominated by yellow risks).
A failure to meet Level 1 requirements prior to minimum lifetime would be treated as a mishap.
Examples: LADEE, IRIS, NICER, and DSCOVR

NPR 7120.8 "class" – Technical risk is high.
Some level of failure at the project level is expected; but at a higher level (e.g., program level), there would normally be an acceptable failure rate of individual projects, such as 15%.

Life expectancy is generally very short, although instances of opportunities in space with longer desired lifetimes are appearing.

Failure of an individual project prior to mission lifetime is considered as an accepted risk and would not constitute a mishap. (Example: ISS-CREAM)

"Do No Harm" Projects – Allowable technical risk is very high.
If not governed by NPR 7120.5 or 7120.8, we classify these as "Do No Harm", unless another requirements document is specified

There are no requirements to last any amount of time, only a requirement not to harm the host platform (ISS, host spacecraft, etc.).

No mishap would be declared if the payload doesn't function. (Note: Some payloads that may be self-described as Class D actually belong in this category.) (Example: CATS, RRM)

Stepping from A, B, ... "Do No Harm" results in:

- More control of development activities at lower levels; people actually doing the work
- More engineering judgment required
- Less control by people who are removed from the development process
- Less burden by requirements that may not affect the actual risks for the project
- Less formal documentation (does not relax need to capture risks nor does it indicate that processes should be blindly discarded)
- Greater understanding required for reliability and risk areas to ensure that requirements are properly focused, risk is balanced to enable effective use of limited resources, and that good engineering decisions are made in response to events that occur in development
- Emphasis on Testing/Test results to get desired operational confidence
- Greater sensitivity to decisions made on the floor

This slide has too much words on it. I will shorten the bullet and add the material I take out to the script.

Recommended: Risk Posture

- Missions will be allowed to have single point failures. The project will not have any spares or engineering units and will go directly to flight build for any custom hardware (ie., protoflight). The project will use COTS hardware in the system design and fly the hardware "as is."
- Project will use a vigorous test program to find any design flaws, poor workmanship, or unacceptable parts for flight. The team will repair, replace or redesign any failed part of the system until the test program is successful.
- Project will maintained a current list of known risks that may impact technical and programmatic commitments. For the purpose of streamlining reports risks will be relayed as issues and concerns.
- A risk assessment should be performed periodically by interviewing each subsystem lead, reviewing their schedule and milestone performance to date. Interdependency and connectivity to other subsystems will be assessed to determine potential risks and impacts to delivery.

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COST & SCHEDULE

Recommended Schedule Characteristics

The first characteristic in the system design approach is a spiral development approach; trading-off requirements vs. hardware cost and schedule

The second characteristic is that commercial off the shelf, "COTS", hardware will be used to reduce schedule risk wherever practical to minimize development time unless cost prohibitive.

The third characteristic is all reviews are to be table top and are not required gates to pass through to continue to the next phase of the project.

First and foremost: SCROUNGE

Are there spare devices available at either your Center or elsewhere at the Agency?

Engage parts/radiation engineers early to help find and evaluate designers "choices".

If you can't find spares, try to use parts with a "history".

If you absolutely need something new, you will pay for the qualification or take the risk.

Challenge: Long Lead Procurements
Recommendations: Use credit card procurements for flight and/or flight-like hardware

Challenge: Phasing (IRAD) financial resources across two different fiscal years.
Recommendations: Identify sources of funding to provide appropriate funding that match the phasing requirements for the duration of the project.

AO Mission Types

- Discovery Program example:
  - Phase A Concept Study – 7 months
  - Selection through launch ~ 7 years
- Mars Scout Program example:
  - Phase A Concept Study – 9 months
  - Selection through launch ~ 6 years
- Small Explorer Program example:
  - Phase A Concept Study – 3 months
  - Selection through launch ~ 3-4 years
- For a facility-class telescope development, 10-15 years depending on technology development required
- For a human spacecraft development (Pre-phase A through Phase D/Launch), on the order of 10-20+ years
- For a Cubesat development (Phase A through LRD), 2-3 years

Example: NG MAYFLOWER – Next Generation CubeSat Flight Testbed

Program Overview for Mayflower a Northrop Grumman CubeSat:

- Objectives:
  - Test next generation CubeSat subsystems
  - Demonstrate NG rapid response space satellite approach
- Architecture:
  - Dragon Trunk 280 km Orbit @ 34.5°
- Top-level Schedule:
  - 4-Month Dev (ATP 1 Feb 2010); 2-Month I&T (Jun-Jul 2010)
  - 2-week on-orbit operation (Dec 10th Launch)
- Accomplishments:
  - Designed, manufactured, integrated, and tested in 6 months
  - Validated all-COTS Design Approach
  - Validated High Capacity Thermal Rejection on Orbit
- Customer: IRAD Team:
  - USC-ISI (Comm), Pumpkin Inc. (Solar Arrays) Applied Minds Inc (Structures & Fab)
- CONOPS:
  - CubeSat deployed by Dragon P-POD
  - ~2 week operational demo mission

Note the aggressive schedule and short mission lifetime

FAILURE ASSESSMENT

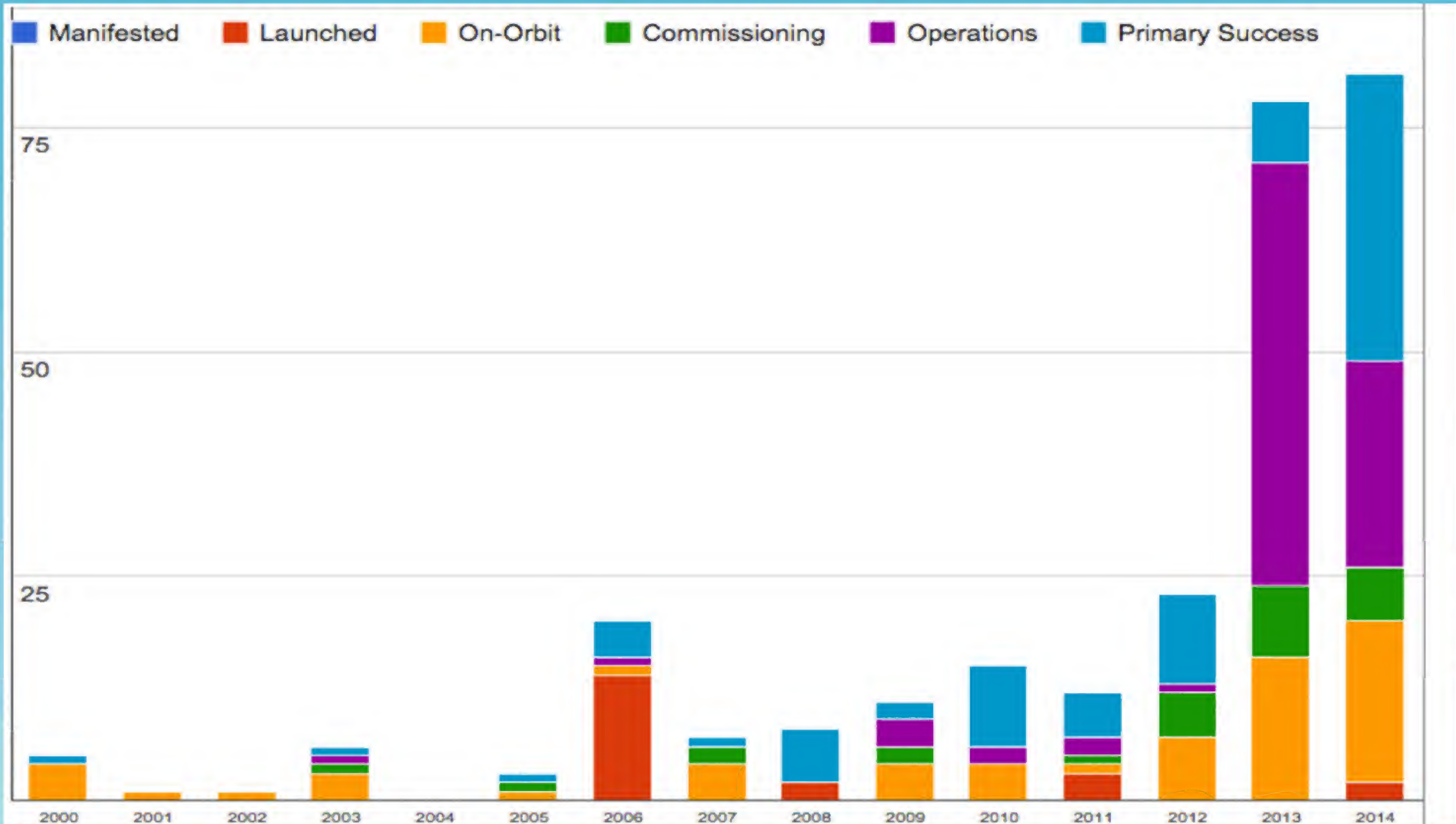
"Culture Busting is required for smallsat to prevail."

Aprille Ericsson, Ph.D.
Small Business Innovation Research (SBIR) &
Small Business Technology Transfer (STTR) Program Manager
Innovative Technology Partnerships Office

It's okay if it's a 10-20% failure rate because there will be more opportunities to build CubeSats. Failure makes better engineers.

Jesse Leitner, PhD
Chief Safety and Mission Assurance Engineer
Code 300

CubeSat By Mission Status



Success Rates of First Launches - All (2000-2014)

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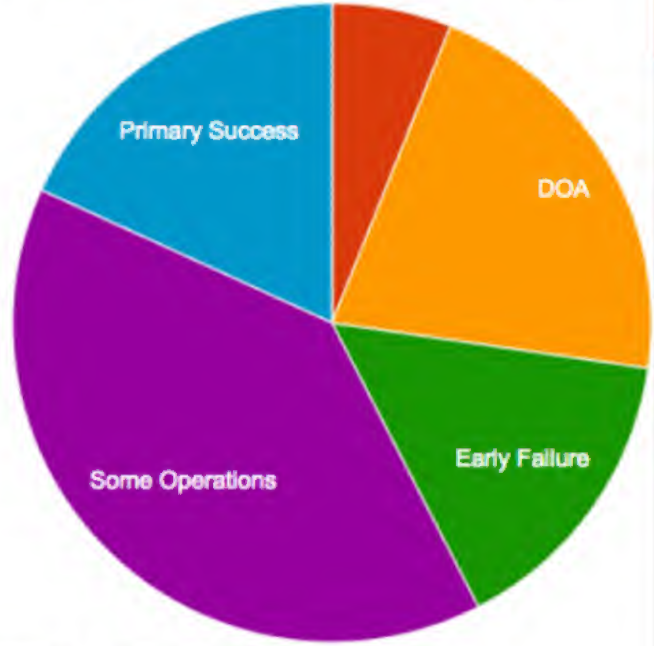
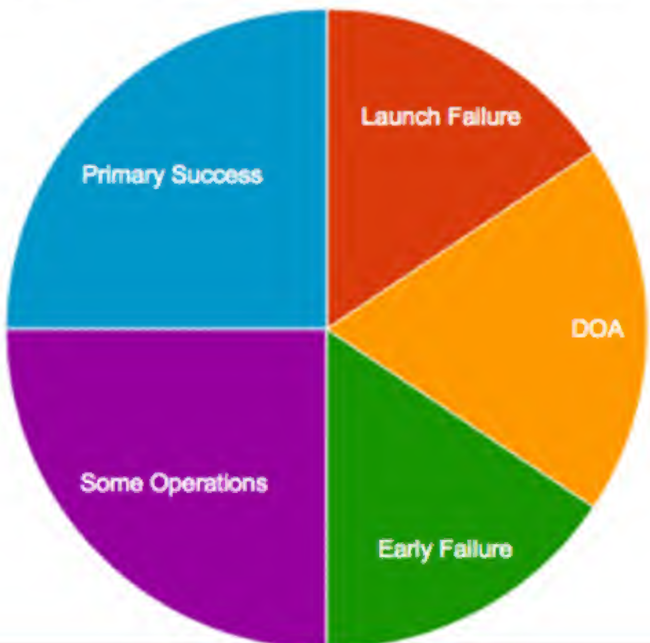
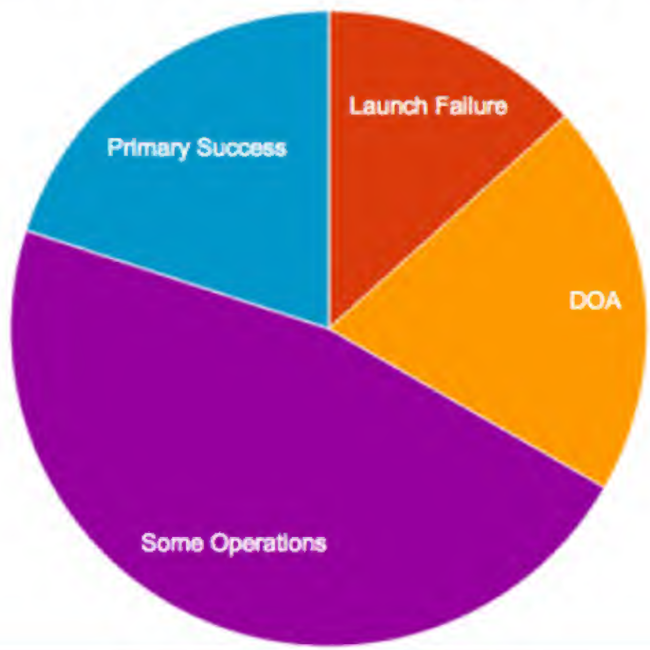


Success Rates of Second Launches - University (2000-2014)



Success Rates of Second Launches - Industry (2000-2014)



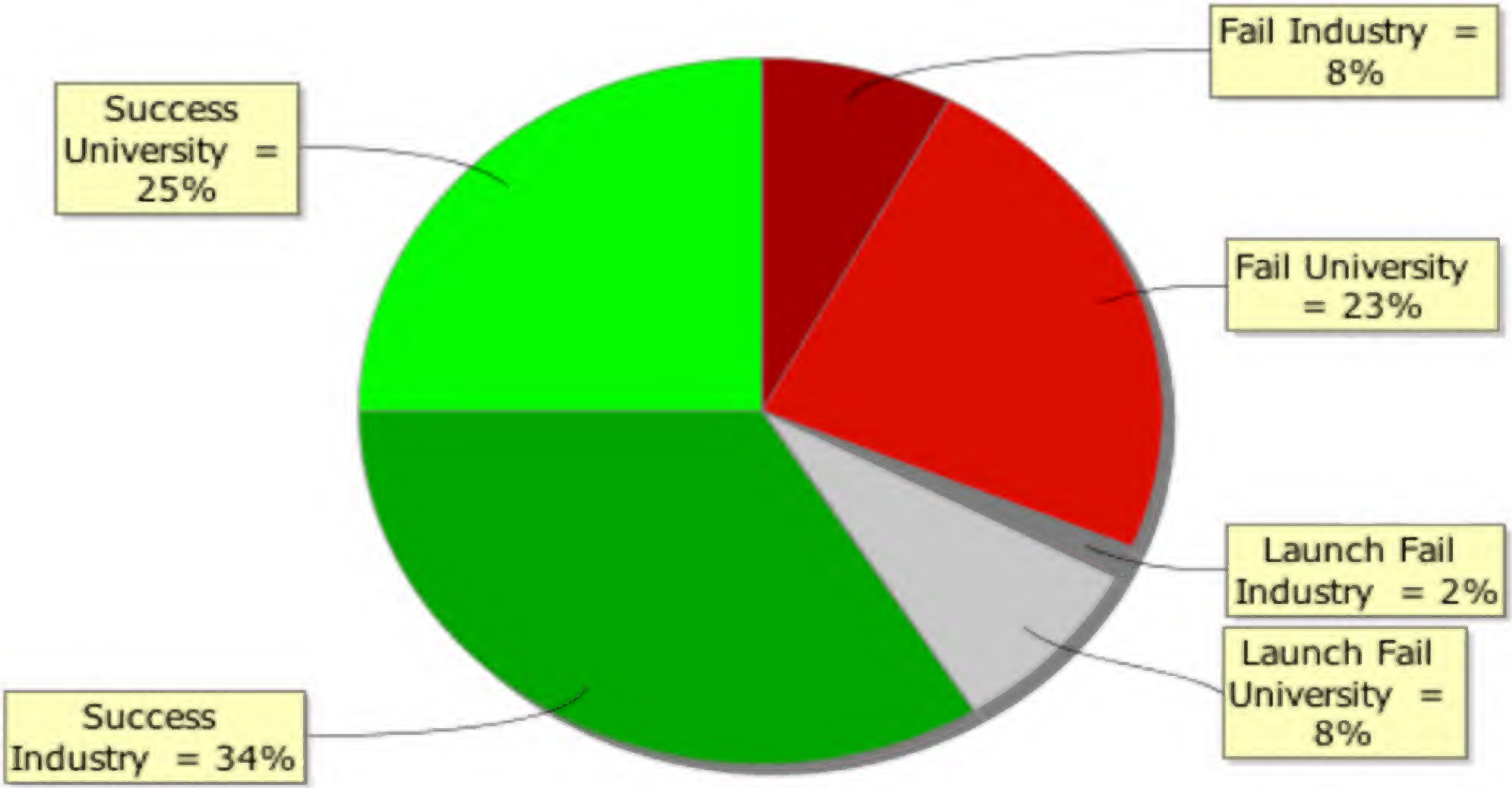


Figure 13. CubeSat Success for University and Industry Missions as Percentage of All Attempted Launches, 2000-2012

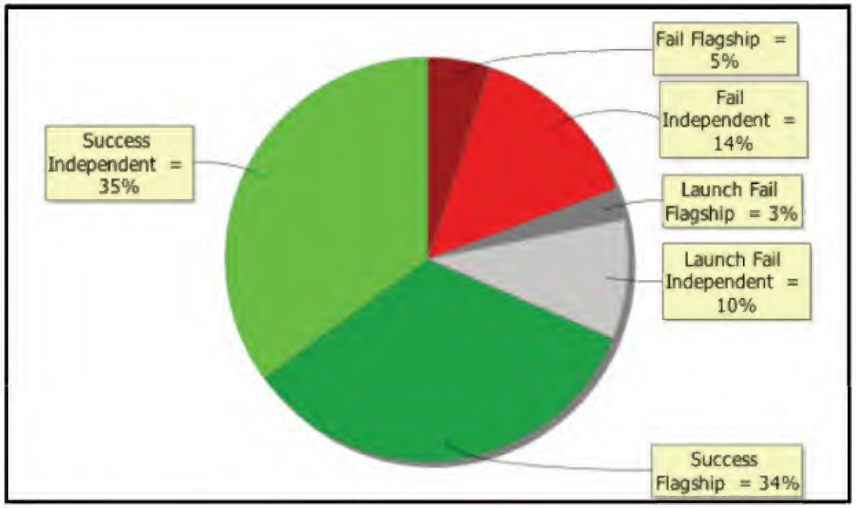


Figure 12: Success Rates by Flagship Category

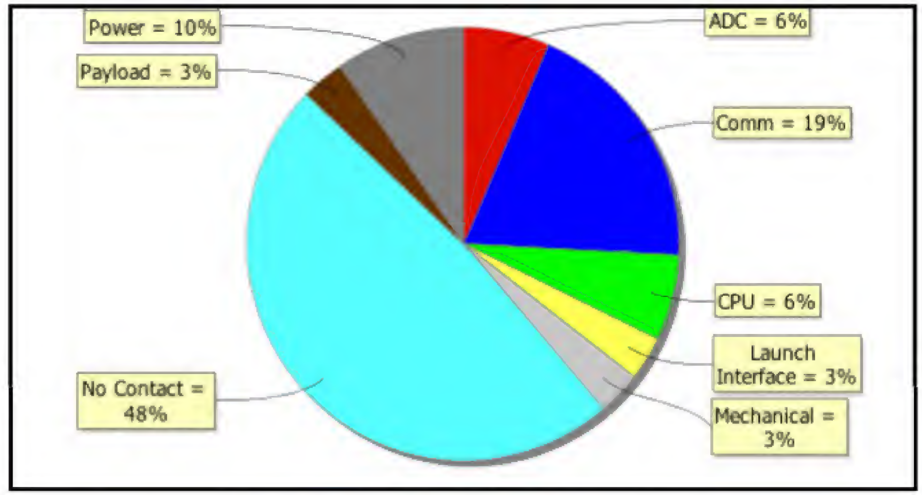
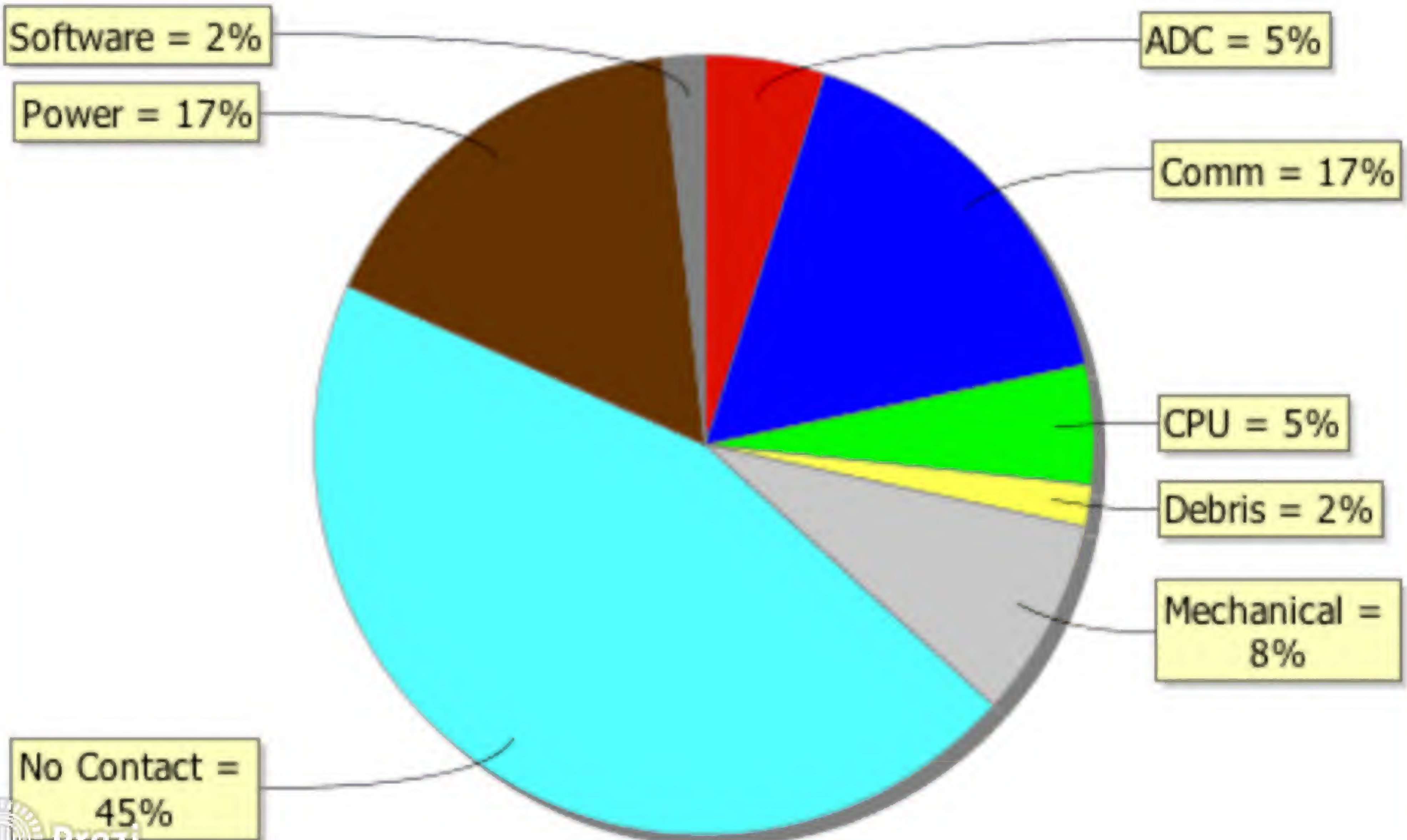


Figure 8: Failure Sources

Whether out of embarrassment, proprietary concerns, or simply a lack of interest, university-class missions do not publish failure reports. The following information is the author's best guess based on news articles and the few published failure reports and has been revised since the last paper. Of the 31 spacecraft we have identified as failing prematurely since 1999 (Figure 8), almost half were never contacted on orbit, thereby precluding a detailed failure review.

Swartwout, Michael. The First One Hundred University-Class Spacecraft, 1981-2008
Swartwout, Michael. The Long-threatened Flood of University-Classed Spacecraft...

Causes for CubeSats' Failures



EXISTING CUBESATS

Inside and Outside of GSFC

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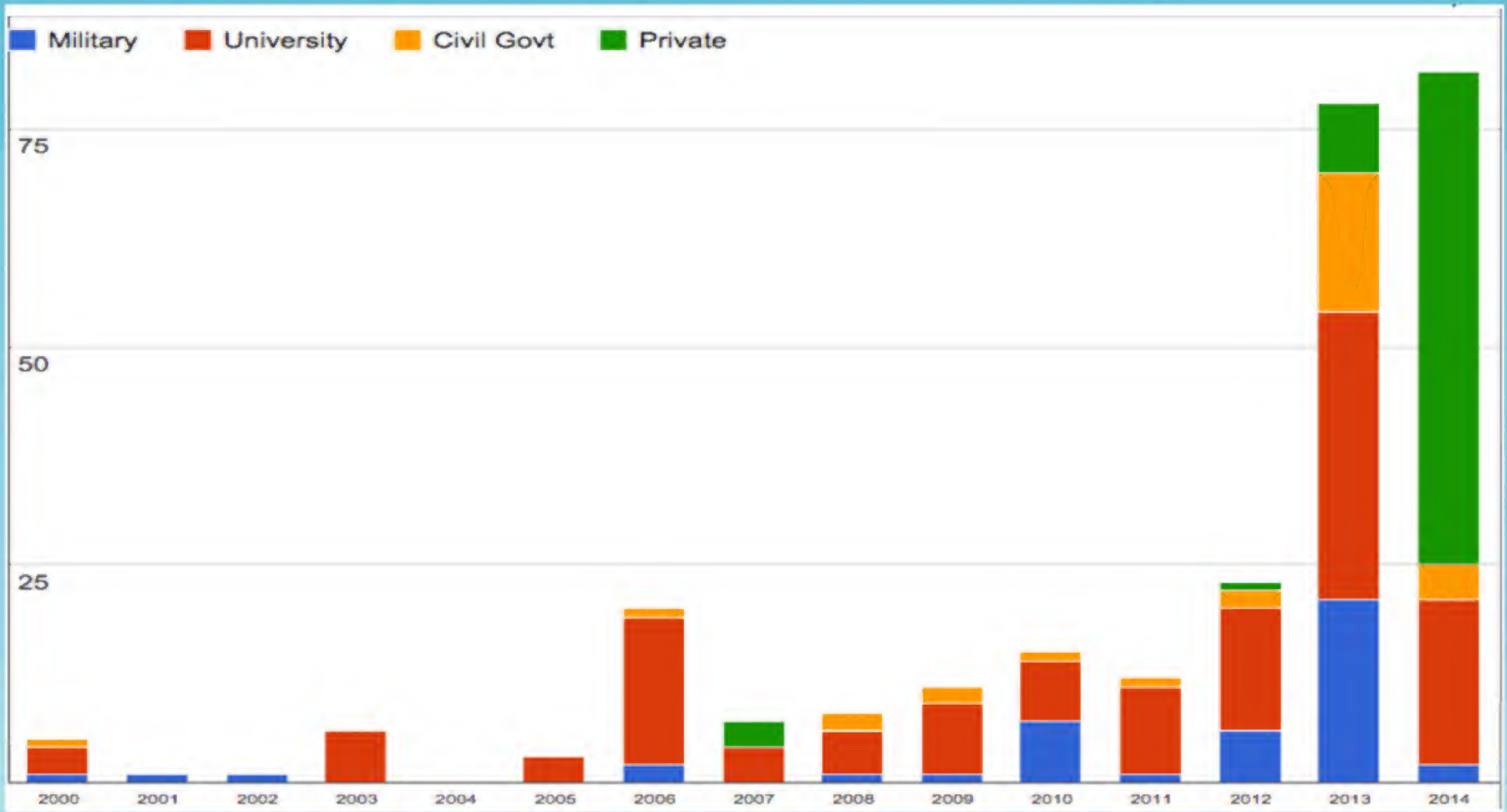
CubeSat by Contractor Type



TESTING CAMPAIGN

What are the critical Technical Reviews and What level of scrutiny is required?

- System Requirements Review
- Critical Design Review
- Pre-Environmental Review
- Pre-Ship Review

Aprille Ericsson, Ph.D.
Small Business Innovation Research (SBIR) &
Small Business Technology Transfer (STTR) Program Manager
Innovative Technology Partnerships Office

"Day in the Life Testing"

- show how powers cycling and environmental cycling affects the cubesat performance.
- "Massage" the cubesat structure as well as prove workmanship of the system.
- *Testing will wring out bad workmanship*
- He also recommends EMI-Compatible testing to see how a possible electronics interference can cause mission failure.

Most failures come from not testing as a system, and if people want to deviate from testing, they have to have great analysis. We always want high margins, but nothing beats testing.

Timothy Trenkle
Senior Applied Engineering and Technology Directorate

Technology Development Opportunities tentative

Ask about what she envisions for her design tool?

The tool that Dr. Pamela Clark's interns are developing is a web-based interface that will when user chooses things like elements, wavelengths, compound, particles, fields, altimetry... it will search for different science instruments needed to find those elements or wavelengths. Some of the science instruments are magnetometer, sensor, sofradir, array, uv photometer (CTIP),cern

Allison Evans own invention is miniature louvers. Dellingr will increase its TRL. It will be not have sunlight in its view factor.
it uses a bimetallic spring
passive system

FUTURE

Of CubeSats at Goddard Space Flight Center

- Implement the CubeSat Swarms/Constellation formation
  - This will probably require new self-automacy technology, better 24 hour transmission, new sensors, and new softwares for the CubeSat
- Mars Mission
- Have a CubeSat Development Lab, like MDL but longer term
- Have CubeSats go interplanetary
- Tethering Flying
- Virtual Flying Laboraties